Journal
of the
Royal Society of Western Australia

Vol. 43 Part 1

1.—Complex Jointing on the Shield Margin near Darlington, Western Australia.

By Michael J. Frost*

Manuscript received 16th June, 1959

Statistical investigation of the jointing in the Precambrian shield to the east of the Darling Fault shows the presence of two joint systems indicating a period of E.-W. compression followed by E.-W. tension. A possible third system and some late slickensides suggest periods of horizontal shear. Other slickensides indicate east-side-down faulting associated with the intrusion of the micro-gabbro dykes. It is suggested that these features are associated with the up-arching and collapse of an anticlinal warp prior to the more westerly collapse which produced the Darling Fault.

Introduction

The Precambrian shield of Western Australia is abruptly terminated to the west by a series of fracture lines of which the Darling Fault is the most important. Immediately east of the Darling Fault is a narrow strip of early Palaeozoic or Proterozoic sediments, and to the west geophysical work suggests the presence of between 20,000 feet and 40,000 feet of sediments (Thyer 1951) of which the top 2,000 feet are known from bores to consist of sandy shales, black shales and calcareous sandstones of Eocene and Cretaceous age. To the east the shield forms a plateau rising to an average height of about 1,000 feet above the western low-lying Swan Coastal Plain. Much of the shield is covered by laterite and is thus not available for direct study but along the margin of the plateau and in river valleys leading from the scarp excellent exposures occur and some of these have been mapped (Clarke & Williams 1926; Prider 1941; Davis 1942; Thomson 1942). From this mapping it has been possible to obtain some idea of the structure of the region and the history of the marginal faulting. One of the most recent attempts is that of Prider (1952) who says "The Darling Scarp then is an expression of a differentially eroded monoclinal structure. It was transcurrent in the late Archaeozoic, but during post-Proterozoic times there was the development of a downwarp to the west (initiated by further movement on the Darling Archaean Fault) which has been progressively sinking and being filled with sediments." He also adduces evidence that there was "a west block south and down movement in Archaeozoic times," which was continued in the late Proterozoic. Other ideas have been put forward by Jutson (1934) and Prider (1941 and 1948). It was with the belief that a statistical analysis of the complex jointing in this region could add to the knowledge of the Darling Fault that this study was undertaken.

Four quarries near Boya Siding (12 miles east-north-east of Perth) in the valley of the Helena River were chosen for study (Fig. 1). These are all in an extensive batholith the petrology, structure and extent of which have been discussed by Wilson (1958). Flow structures are not common near the quarries but where observed flow layers strike predominantly N.-S. and dip steeply to the east. Locally two varieties of granite may be distinguished, a coarse-grained porphyritic microcline granite and a fine even-grained granite of similar mineralogical composition in which the former is xenolithic. In other areas an intermediate variety is found. It seems probable that these do not represent separate granites but only repeated intrusion of deeper material into an upper partly solidified crust. Both are cut by pegmatites. The area is also crossed by numerous shear zones, many partially or completely silicified, varying in width from several feet to several chains. The majority of these have a NNE.-SSW. strike and are believed to be of earlier origin than the main jointing. Of later origin is a swarm of NNW.-SSE. striking micro-gabbro dykes. End-stage products from these have coated the earlier formed joints and the dykes themselves have caused limited alteration of the adjoining granite but the total effect has been slight.

Methods of Compilation and Study

Field Methods

In this study it was soon realised that natural exposures and shallow cuttings seldom gave data of sufficient accuracy or gave a sufficient number of joints for any but the most important

* Department of Geology, University of Canterbury, Christchurch, New Zealand. Formerly, Department of Geology, University of Western Australia, Nedlands, Western Australia.

joint systems to be evaluated. For this reason four quarries distributed as evenly as possible over the area were chosen for detailed investigation. Their location is shown on Fig. 1.

In each quarry as many joints as possible were measured. In order to avoid as far as possible subjective selection the following technique was used. In any one quarry on each level a number of points on the wall were marked and later mapped by tape and compass. These points were chosen on a horizontal plane, to within several feet, in such a way as to make the lines between any two successive points close to and approximately parallel to the nearest quarry wall. Offsets were taken from these lines to the walls, and for every joint along these lines the dip and strike were measured in the usual way. In irregular joints the strike and dip of the main surface rather than the mean was taken. Joints were not measured when there was any possibility that they had been disturbed by blasting, soil creep, etc. All planar features such as dyke walls, pegmatites, etc., were also measured. All measurements finally used were made by the author.

At the same time as the dip and strike of each joint was measured the following features were noted:

Texture—the relative roughness or smoothness of the joint face.

Planeness—the degree of approach of the joint surface to a plane, or the lack of curvature.

Veneer—the nature and thickness of the veneer on a joint.

Length—estimation of relative length.

When slickensides were present their trend and plunge were measured and recorded. In the majority of joints only a few of these features could be observed.

It is of interest, having shown the methods adopted to avoid bias, to examine the possibilities for bias that remain. The direction and vertical range of the line of traverse must have an important effect. Joints with strikes parallel to the line of traverse will obviously be biassed against in favour of those with strikes at an angle. This is a bias that has been largely ignored by previous authors. The bias for the near vertical joints has been minimized to a large extent by measuring all the joints in a quarry, thus having traverses with a number of different bearings. In those examples where this was not possible, or where the quarry was distinctly elongate, this bias must still be taken into consideration.

Flat-lying joints with strike parallel to the traverse present a more serious problem, as it is obviously impossible to traverse vertically as

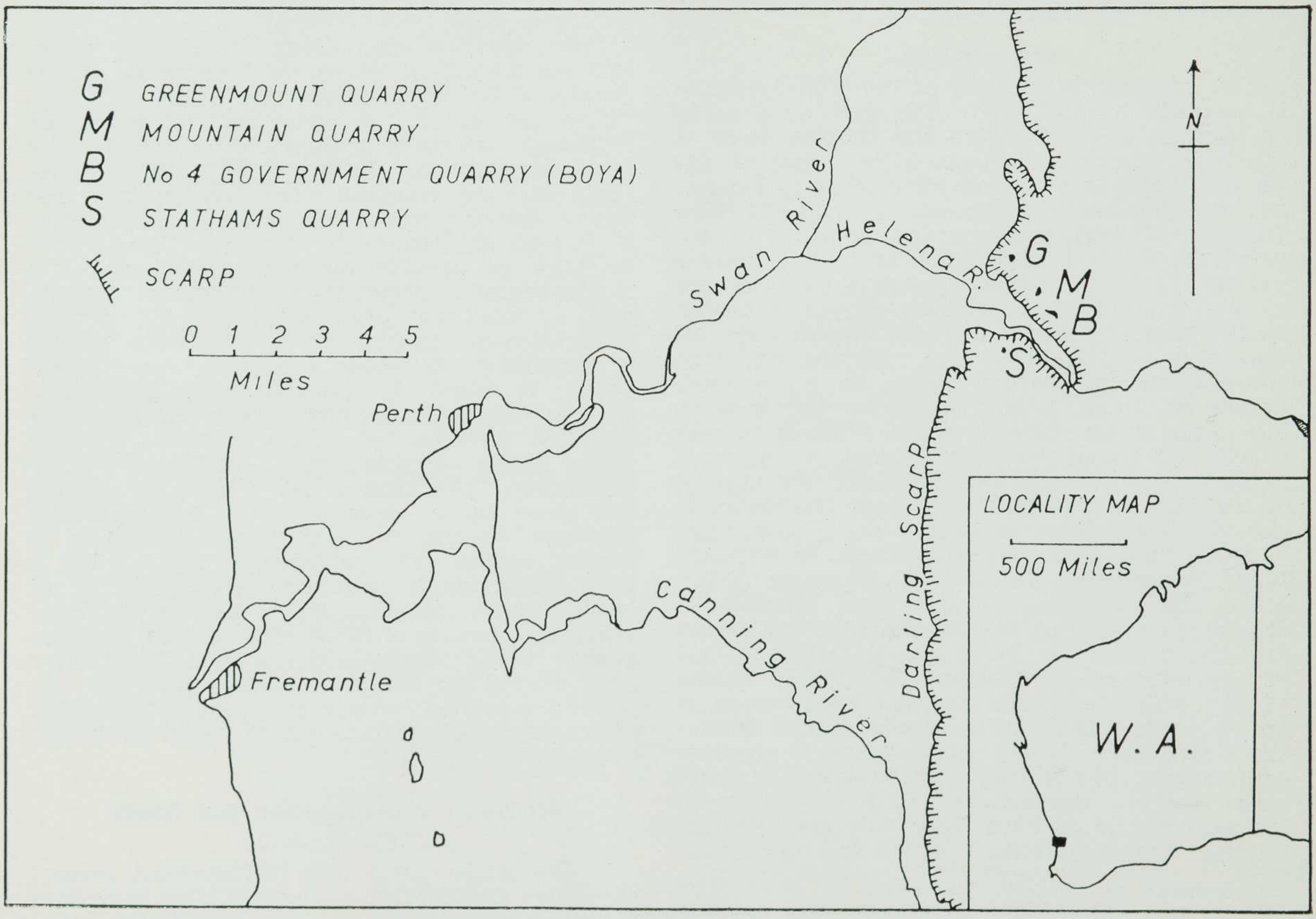

Fig. 1.—Map showing location of quarries in relation to the Darling Scarp.

far as horizontally. An effort was made to decrease the effect by specially searching for and measuring every exposed flat-lying joint. As, however, many were curving, and others difficult or impossible to reach, this probably remains a major bias. Nevertheless its structural importance must not be over-emphasised because the joints are possibly of little structural significance and may not continue to be present at depth.

Another possibility for bias, more important because it is difficult to evaluate, is that some joints may not be visible on a freshly broken surface. This may be due to welding by a solid veneer so that the rock fails to break along the joints or it may be due to preferential breakage along certain major joints. The effect of this bias was slightly diminished by attempting to follow up any traces of joints until they could be measured. Many, however, were probably missed and others could not be so followed up. Field observation tends to indicate that in this study the main effect of the bias would be to slightly flatten some of the more important maxima, as the tendency for joints not to be visible tends to be more a factor of the position of the blasting charge than of the type of joint.

Other ways in which bias may have occurred are believed to have had little significant effect in this study. It is, however, important to realise that the joint numbers obtained are proportioned not to the number of joints in the region, as might at first be expected, but to the area of the joints in the region. This is the logical result of cutting planes, which field evidence shows to be finite, by lines and counting the number of intersections. It is of considerable importance in that it means that small joints have little chance of being recorded.

Laboratory Methods

The data were next analysed in order to discover if—

(1) there were statistically significant maxima in the joint directions;

(2) the joints forming these maxima differed in surface characteristics;

(3) the positions of these maxima varied significantly in different quarries.

For this purpose it was obviously necessary to plot the data in a way capable of showing their three dimensional properties. Strike and dip analysis are only applicable when some other method has shown that their use does not result in a serious loss of information.

Two methods are in use for this purpose. These are plotting the poles of joint normals on an equi-area projection (Billings 1942) or on a rectangular projection (Pincus 1951). Both were tried and it was found that the equi-area projection contoured by a method similar to that of Haff (1938) using a 1% counting circle was not only easier to interpret but had a plotting accuracy more commensurate with the accuracy with which the joint data could be obtained .

The standard error of the mean was determined for several representative groups and was found to be below 2° in each case. Modes, rather than means, were used in later work because they could be found easily by trial and error with the counting circle.

The modes having been obtained the planes which they represent were plotted on the cyclographic projection in order that their angular relations might more easily be appreciated.

In all plotting the upper hemisphere was used.

The surface features of the joints were analysed by the following method. The contour diagram was divided into a series of areas, each containing one maximum, bounded by lines of longitude and latitude. These lines were chosen in such a way as to pass through areas of minimum joint concentration. In addition a central area was chosen to include all flat-lying joints. The number of joints having definite standards of roughness, etc., was then counted in each of these groups and in one group which consisted of joints not fitting in any of the defined areas. In this way, information was obtained as to whether one maximum contained joints with surfaces or length noticeably different to those contained by any other. Due however to the large number of joints on which it was impossible to observe the surface characteristics, which may or may not bias the results, caution must be used in interpreting the results. In order to assist in visualising these data they were simplified into pairs of alternatives and the frequencies plotted on square root charts.

The slickensides were plotted by the following method. Since each slickenside must lie in the plane of the joint on which it was observed, it is just as important to know the orientation of that plane as to know the orientation of the slickenside. For this reason the poles of the joints were plotted in the normal way, then from each pole a short line was drawn parallel to the trend of the slickenside. These lines were arbitrarily drawn on the side of the point towards the primitive circle. When the direction of movement for any one slickenside was known, a small arrowhead was added pointing in the direction the outside block (i.e. assuming the joint to be tangential to the sphere) had moved. This method of representation was found to considerably simplify visualisation of the data, so much so that the loss of accuracy for slickensides on joints with steep dips was not felt to justify its rejection. When necessary, the poles of these ambiguous slickensides could also be plotted as well as their trends.

Jointing in Individual Localities

Joints in Greenmount Quarry

Greenmount Quarry is in the north-west of the area and is about one mile east of the Darling Fault. It is slightly elongate in a north-south direction. A wide vertical micro-gabbro dyke and several smaller dykes outcrop on the floor and the north wall of the quarry. Pegmatite dykes varying from ½in. to almost a foot wide are well exposed. Several of the smaller pegmatites are offset as much as several inches by minor movements along joint surfaces. A zone of closely spaced jointing crosses the west half of the quarry in a north-south direction. One hundred and ninety joints were measured.

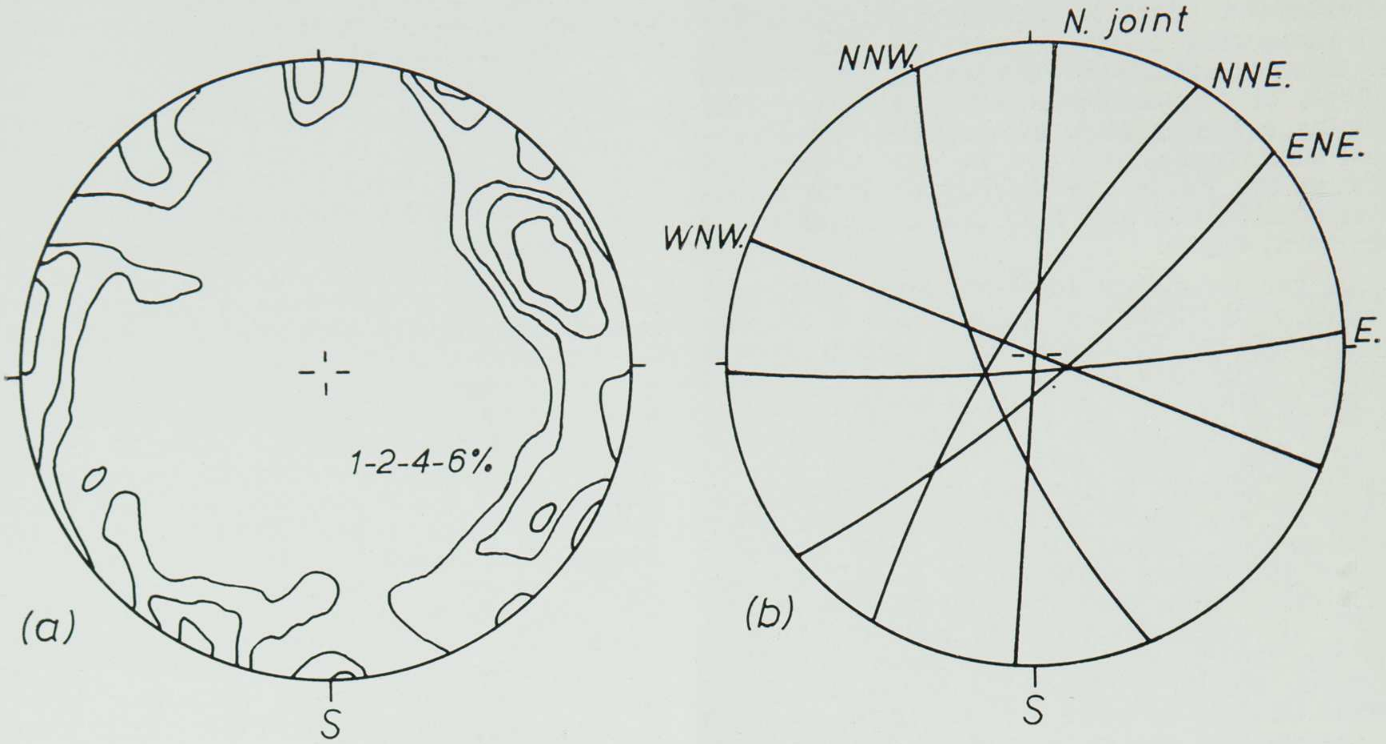

Fig. 2.—Joints in Greenmount Quarry.
(a) Equi-area contour diagrams (upper hemisphere) of 190 joint normals. (b) Cyclographic projection (upper hemisphere) of planes representing modes in Fig. 2a.

As may be seen from the contour diagram (Fig. 2a) the poles of the joints fall into six well defined groups, which are represented by modes varying in point density from 3% to 13%. When the planes represented by these modes are plotted on the cyclographic projection (Fig. 2b) a definite pattern can be recognised. Briefly the pattern may be described as an E.-W. striking plane cut in one line by two planes making acute angles to the north and south, in another by an almost N.-S. plane and in a third by two planes making acute angles to the east and west. For convenience these planes will be called after their approximate strike directions, i.e. N., NNE., WNE., etc., as shown. Where it is possible to correlate joints in other quarries with these the same terminology will be used even if the name no longer suggests the approximate strike.

The relationships between the joints are difficult to see except where erosion or blasting has exposed a clean horizontal surface. Where such occurs the most obvious feature is the tendency for the joints to cross each other with no offsetting, curving or change of strength or veneer. Another feature is that the dominant NNW. joints often terminate or are interrupted by a series of joints from several inches to over a foot long and "en echelon" in line with the orginal joint. These are turned clockwise about 10° with respect to the original joint. This is a typical arrangement of tension fractures and may be taken as evidence of a dextral transcurrent shearing stress having occurred in the plane of the NNW. joints. Small rough joints are occasionally found between two close NNW. joints: these are approximately vertical and approach the E. joints in strike. They may also be associated with them in origin. The E. joints are locally associated with joints that are almost vertical and approach the N. joints in strike. These are seldom more than a foot long and may be no more than a few inches. They are sometimes found in lines along the E. joints and sometimes continue past the end of the joints. These small joints are also found distributed throughout the rock with no obvious associations. Due to their small size they probably do not produce a significant effect on the contour diagram.

The occasional pegmatites are often found to be faulted by the NNW. joints. The components of the faulting are not often determinable but the apparent displacement on a horizontal plane is always sinistral. A graphical study of the data on the surface features of the joints indicated that they fall into several groups. The E. and NNW. joints fall into what might be called the perfect group, most being long, flat and with black veneer. The NNE. joints approach this closely being mainly long with black veneer but occasionally not so smooth or flat. The flat-lying joints and possibly ENE. fall into the group with the opposite tendencies, rough, and short with many lacking veneer. In between these extremes lies a group, including the WNW., N. and possible ENE. joints. This seems to indicate that there is a definite difference in conditions of formation between the two diagonal sets and also between the N. and the E. and the flat-lying joints.

Joints in Mountain Quarry

Mountain Quarry lies towards the centre of the area and is about 1½ miles east of the fault. Three levels are present. The quarry has a NNE. elongation and is cut by a large number of micro-gabbro dykes and pegmatites. Fifty-six joints were measured.

As may be seen from Fig. 3a there are four modes, one reaching the remarkable point density of 24.5%, and two very poorly defined modes. When these were plotted on the cyclographic projection, it was seen that they formed a pattern strictly comparable with that of the joints at Greenmount Quarry. This not only confirms the significance of the two very poorly defined maxima, but also indicates that if every maxima is to be defined 50 joints are scarcely sufficient and where possible 100 at least should be measured.

Although the angular difference between the patterns are statistically significant the small similarity is surprising. The only differences are the absence of the N. joints which is probably not due to the small number of measurements, and the presence of a set of relatively flat-lying joints. The relative though not the absolute heights of the maxima are also somewhat similar although the predominant development of the NNW. group is here emphasised.

Joints in No. 4 Government Quarry (Boya)

No. 4 Government Quarry (Boya) lies towards the centre of the area and is about 2 miles east of the fault. The quarry consists of a long face with a north-north-west trend, and a minor north-west face. Only one level is accessible. These features will probably bias the joint statistics as already indicated. Eighty-six joints were measured.

The quarry is cut by three relatively small micro-gabbro dykes and several pegmatites.

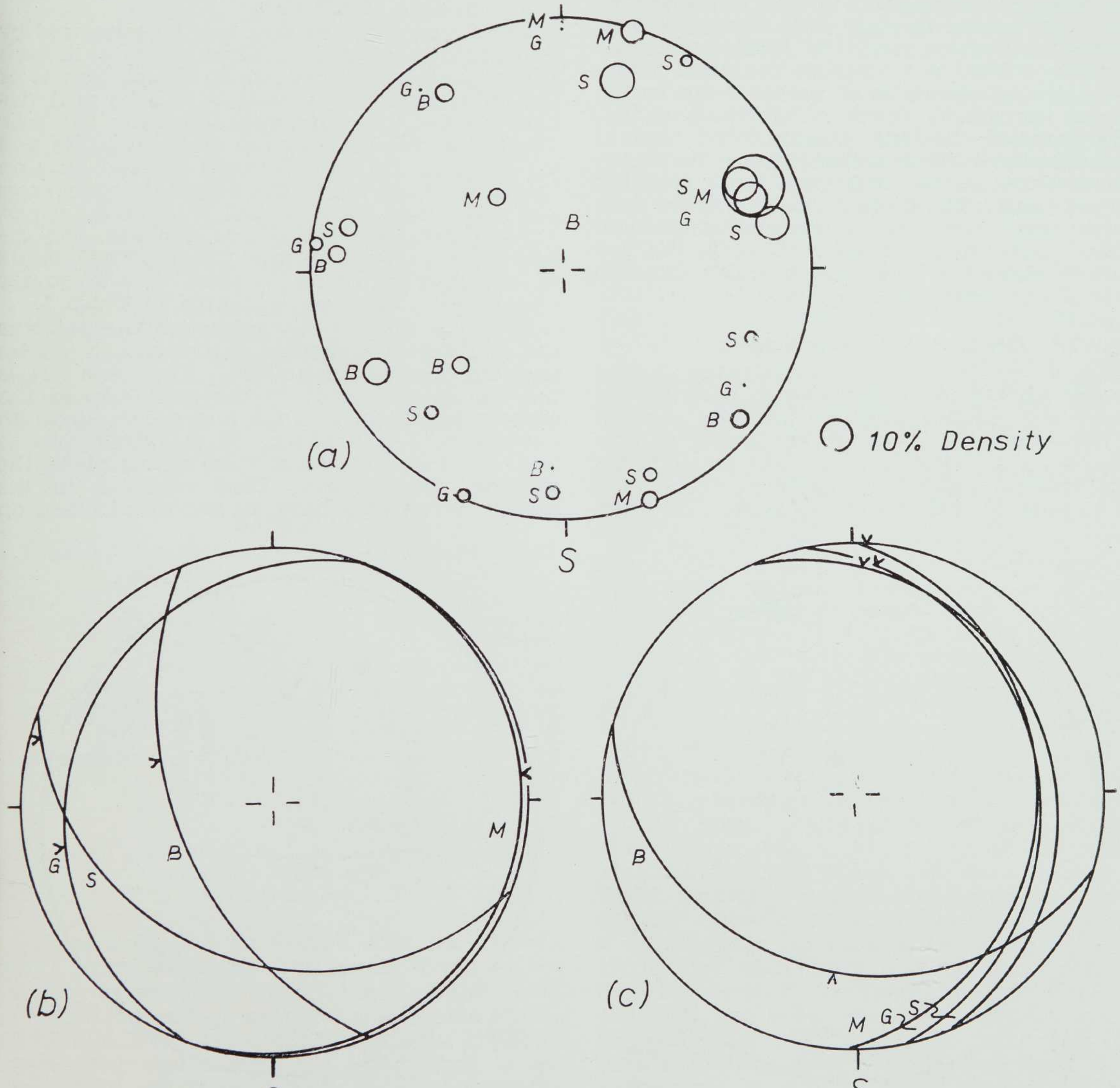

Fig. 3.—Composite diagrams (upper hemisphere). See Fig. 1 for legend.

(a) Equi-area projection of modes of joint orientation from the four quarries (radius of circles proportional to modal densities).

(b) Cyclographic projection of theoretical AC stress planes and B axes for ENE. and WNW. joints.

(c) Cyclographic projection of theoretical AC stress planes and B axes for NNE. and NNW. joints.

As may be seen from Fig. 4a the joints in this quarry fall into seven groups. When plotted on the cyclographic projection it may be seen that these form the pattern with which we are already familiar and in which the flat-lying N., E., WNW., ENE., NNW. and NNE. sets can readily be identified. It may be noticed however that the angular relation and positions in space are significantly different to either pattern so far observed. That this pattern has persisted through three quarries with each pair of diagonal joints intersecting almost exactly on the plane of the E. joint is strong evidence that the standard error of the mode ($< 2°$) was not underestimated. Again, the relative values of the modal densities are also roughly comparable. The NNW. is dominant, the N. is important (7%) contrasting strongly with its absence at Mountain Quarries, and the NNE. is greater than the WNW. in reverse of the usual order. Both these effects are most probably due to the bias of the quarry direction discussed earlier, it being noted that this quarry would tend to emphasise the north-trending joints while Mountain Quarries would emphasise those trending west and east. The surface characteristics were studied and were found to be similar to those of the joints at Greenmount Quarry, but not so well defined. This was probably because fewer joints were measured.

Joints in Stathams Quarry

Analysis of joint data at Stathams Quarry revealed an extremely complicated pattern. Although this pattern could be partially resolved by considering the quarry to consist of two separate parts divided along the major dyke, interpretation was still so ambiguous that it is not considered in detail in this paper. However, the results from the east half of the quarry are quoted in the summary for completeness even though they must be accepted with extreme caution.

Comparison of Jointing in the Four Quarries

The jointing in each of the quarries can be compared from a variety of viewpoints. Among these are the angular properties of the joint pattern regardless of their orientation; the orientation and relative importance of the individual joint planes; and the orientation of the principal axes of the hypothetical stresses that may have caused the joints. Any two of these will be mutually independent and together comprehensive but a third is necessary for complete understanding of the data.

The actual patterns may best be compared by measuring corresponding dihedral angles in each and tabulating the results. If the pattern is of the Greenmount type then it will be well defined by the following measurements: the four dihedral angles between the diagonal joints and the E. joint, the angle between the two lines on the E. joint on which the diagonal joints cross and the angle between the N. and S. joints. These measurements and, as a check, the dihedral angle between the two diagonal joints of a pair were therefore used as a basis for comparison. They are tabulated in Table 1.

It will be noticed that, although the patterns are qualitatively similar, corresponding angles may differ by as much as 30°. This, it is felt, is not due to variations in the properties of the granite as other evidence has shown these to have a negligible effect. It is rather due to local variations in the stresses acting along the principal stress axes. That variation in the relative stress may have an important effect on

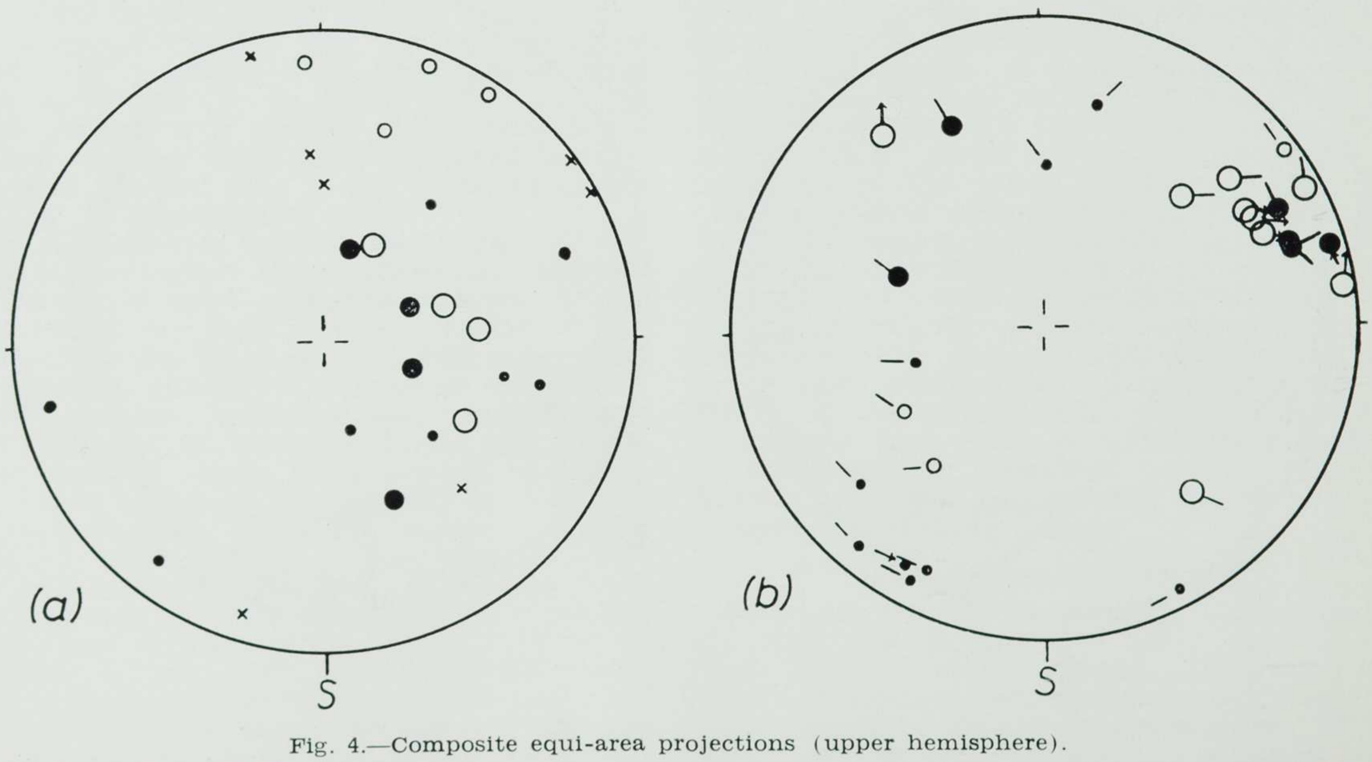

Fig. 4.—Composite equi-area projections (upper hemisphere).

(a) Pegmatite normals.

(b) Joint normals and associated slickensides. Large circles = Greenmount Quarry, large solid circles = Mountain Quarry, small circles = No. 4 Government Quarry (Boya), small solid circles = Stathams Quarry, crosses = other nearby localities.

the angle between the shear planes has been demonstrated by Parker (1942) who shows that the angle decreases when the stress acting along the axis of minimum stress becomes tensional, and by Grigg (1936) who suggests that the angle increases under high confining pressure. Another point of some interest is that in no quarry are the diagonal joints exactly bisected by the E. joint, the two angles on either side of the E. joint differing by up to 10°, and the larger angles always being associated with the same joint. This may indicate that the E. joint was controlled by a then present 'rift' direction. The average dihedral angle between the diagonal joints is close to 60° which if the joints are considered as shear planes is close to or little less than that which would be expected (Hilgenberg 1949). It is of interest to note that if the two pairs of diagonal joints were not of contemporaneous origin, as the evidence seems to indicate, and if the one set in no way offsets or deflects the other, that it might be expected that the one which was later would be the more regular in that it would be affected by fewer stresses. If the data for the two diagonal sets are examined it may be seen that the WNW.-ENE. set is the less regular in every way. This may be taken as some indication that it was the earlier to form. Other points are, the surprising difference between the ENE.-WNW. joint relations in the Mountain and Boya quarries which is not reflected in the NNE.-NNW. joint relations, which may possibly be explained as above, and the facts that the dihedral angle between the N. and E. joints is about 90° and the angle between the two lines along which the diagonal joints cross is about 30° varying from 15° to 38°.

TABLE 1

Table of dihedral angles between modal joint planes in various quarries.

Joints	Greenmount	Mountain	Boya	Stathams	Mean Directions
E.-ENE.	38	20	53	(60 to N.)	37 ± 11*
ENE.-WNW.	64	37	95	(116 to N.)	65 ± 20
E.-WNW.	26	17	43	(56 to N.)	29 ± 10
E.-NNE.	60	(65?)	52	72	61 ± 7
NNE.-NNW	128	(134?)	105	149	128 ± 15
E.-NNW.	68	68	53	77	66 ± 7
N.-E.	94	....	86	95	92 ± 4
B-B[1]	30	15	38	35	30 ± 7

B and B[1] are the hypothetical axes of intermediate strain on the E. joint.

* Average deviation.

Support for the suggestion that the WNW.-ENE. joints were there earlier is found in the jointing of one of the silicified shear zones. Here, although the rock is well jointed only the NNW., NNE. and EW. sets are represented. Although alternative explanations are possible, it is believed that silicification took place between the two periods of joint formation.

The poles of the planes forming the joint patterns of the four quarries are plotted on the equi-area projection of Fig. 3a. It is useful to remember when reading this diagram that, if we accept a standard deviation of the mean of 2°, a difference of 5° may be considered evidence and a difference of 10° may be considered proof of a significant variation. It will be noticed that significant variation takes place in the position of almost every joint. The most interesting point is the close grouping of the NNW. joint sets, the dominance and persistence of which has already been noted in the field. This seems to suggest that they were later reinforced, or possibly even reoriented by a strong and unusually constant force after their original formation. It may also be significant that the joint set with the next highest maximum is the WNW., an adjacent set.

The last method in which the joint patterns will be compared is that based upon the theoretical positions of the principal axes of the stresses which may have produced the joints. This, regardless of its theoretical implications which will be discussed later, is a very convenient way of comparing the orientations of the patterns as distinct from the planes. For this purpose it is assumed that the diagonal joints represent shear planes intersecting on the intermediate stress axis. It is also assumed that the axis of maximum stress is normal to the axis of intermediate stress and in the plane containing the axis of intermediate stress and bisecting the dihedral angle between two diagonal joints. The axis of least stress is taken as normal to this plane. As will be shown later, these assumptions are justified and probably approach the truth. The three principal axes are by construction at 90° to each other. For this reason a plane containing two of the axes and the direction of one of the contained axes is sufficient to fix the position of all the axes. For the purpose of comparison the two diagonal sets were treated separately, i.e. those with the acute angle to the north were plotted on one diagram (Fig. 3b), the others on another (Fig. 3c). Each was shown by plotting, on a cyclographic projection, the plane containing the axes of maximum and minimum normal stress and on this plane drawing a 'V' to point to the pole of the axis of maximum normal stress. This may be considered as the cyclographic projection of a simplified version of the figures used by McKinstry (1949) to illustrate stress relationships.

The close similarity, in both diagrams, of the directions for Greenmount and Mountain Quarries is noticeable. In that for N.-S. maximum normal stress Stathams is also similar while Boya differs only in the plunge of the axis of maximum normal stress. In the diagram for E.-W. maximum normal stress there is a much greater variation in the strike of this axis and a considerable variation in the positions of the planes for both Boya and Stathams Quarry. This rather tends to support the argument that the NNE. and NNW. diagonal joints are of later formation, although it must be noted that these data and those used before are to some extent correlated. It may be noted that a 40° west down rotation on a NW.-SE. axis brings all the Boya data into a position comparable with that from other quarries. It might also be noticed that a similar rotation of only 35° will serve to bring the errant data of Stathams into conformity if applied to this only.

Other Data

Plotting the pegmatites from the entire area on one diagram (Fig. 4a) brings out two points; the pegmatites are obviously not connected with the present joint system and the angular differences between the pegmatites from the Boya Quarry and from other localities are of the same direction and order of magnitude as those of the joints.

The slickensides plotted on the stereographic projection (Fig. 4b) also show an interesting feature. Although they are found on various joint sets they fall into two well-defined groups, one with approximately E.-W. trends indicating movement of the east block down, and the other with approximately N.-S. trends indicating movement of the east block to the north. These groups are even clearer when the data for the various quarries are examined separately. The relative age of the two periods of slickensiding and the validity of the first is indicated by the fact that some of the dykes show curvature of contraction joints consistent with east-block-down as the main component of movement. Since all the slickensiding is in the micro-gabbro intrusion end-stage products and is therefore post dyke-intrusion, this indicates that the east-block-down movement was the earlier.

Summary and Discussion

After the consolidation of the granite, intrusion of pegmatites, and production of the main shear zones five periods of stress are recognised. The first three resulted in the production of reinforcement of joints, the last two in the production of slickensides. Evidence has been found supporting a given sequence in these. If we accept the view based on field and laboratory evidence that the acute angle is bisected by the axis of maximum pressure, it is possible to postulate a highly probable stress orientation for most of these periods. The loadings which could have caused such stress orientation and the geological conditions which in their turn could have caused such loadings are however very numerous. Only those which seem to best fit the evidence in the limited area examined and the evidence of the general geotectonics of this part of Western Australia will be discussed.

Taking the oldest two joint systems first, they could have been produced by E.-W. compression followed by E.-W. tension. This is a common sequence either where dominant pressure is released allowing the built-up pressure at 90° to it to become dominant, as may have occurred throughout the West Australian Precambrian block, where E.-W. minor folds cross N.-S. major folds; or where the arching due to folding allows tension to develop on the crests of the major anticlines. In view of the fact that the area here is a major batholith the latter is felt to be more probable. There is some evidence that silicification of shear zones, which might be of more than one age, occurred between the formation of these two joint patterns.

This jointing seems to have been followed by another problematical joint set. The most prominent and uniform in the area, it seems to have had a late origin, yet in position and in the field it appears simply as one set of the second joint pattern just discussed. Since it is represented only by a single set, it might tentatively be suggested that it was formed by a shearing stress possibly, in view of evidence by previous workers for similar movement, sinistral.

The interpretation of slickensides is always fraught with difficulties because there is no way of telling if they are associated with major or minor movements. Two sets of slickensides were observed, both obviously post-dyke-intrusion. No internal evidence was available to suggest their sequence. One set indicates very clearly predominantly east downward vertical movement while the other indicates sinistral shearing movement. They were necessarily formed by two separate forces. There is internal evidence that the east downward movement is the earlier and it seems reasonable to correlate this movement with the formation of the micro-gabbro dykes, both being consequent on the collapse of the up-arched structure. If this is justified then the other set may represent later return of the sinistral shearing movement. There is no record of events later than this.

Summarising it may be said that the following history seems probable. Intermittent sinistral shearing stress seems to have existed since early Precambrian. Evidence for this has been detected by Prider in the folded Archaean Jimperding Group, the Proterozoic or early Palaeozoic Cardup Group, the shear zones and the dyke formation, and by the present author in the jointing and slickensides. Superimposed on this was a major east-west compression which produced up-arching. Silicification may have occurred at this stage. The anticlinal structure later collapsed with synchronous intrusion of micro-gabbro dykes. Although these stresses may have been forerunners of those which later produced the main Darling Fault no direct connection is claimed. However recent stratigraphic and structural research has indicated that the zone of collapse may have moved toward the west with the subsequent production of the Darling and more westerly faults. If this is so it seems that the continental margin of Western Australia shows evidence of up-arching and the collapse of not only the centre of the anticlinal structure but later of the continental margin on one side of it.

Acknowledgments

This work was carried out at the Department of Geology, University of Western Australia, and formed part of the study for a B.Sc. (Hons.) degree (Frost 1952). I am indebted to Mr. K. C. C. Tiller for the suggestion that the study of the jointing in this area might provide a clue to the history of the Darling Fault. My grateful acknowledgements are due to Professor R. T. Prider and Dr. A. F. Wilson for their generous assistance and encouragement both during the research and the writing of this paper, and to many others who assisted in various ways.

References

Balk, R. (1937).—Structural behaviour of igneous rocks. *Mem. Geol. Soc. Amer.* 5.

Billings, M. P. (1942).—"Structural Geology." (New York: Prentice-Hall.)

Clarke, E. de C., and Williams, F. A. (1926).—The geology and physiography of parts of the Darling Range near Perth. *J. Roy. Soc. W. Aust.* 12: 161-178.

Davis, C. E. S. (1942).—The geology and physiography of the Gosnells area. *J. Roy. Soc. W. Aust.* 27: 245-264.

Frost, M. J. (1952).—The fracture systems of the Darling area. Unpub. thesis, Univ. W. Aust.

Grigg, D. T. (1936).—Deformation of rocks under high confining pressures. I. Experiments at room temperature. *J. Geol.* **44**: 541-577.

Haff, J. C. (1938).—Preparation of petrofabric diagrams. *Amer. Min.* 23: 543-574.

Hilgenberg, O. C. (1949).—"Die Bruchstruktur der Sialischen Erdkruste." (Akademie-Verlag: Berlin.)

Jutson, J. T. (1934).—The physiography (geomorphology) of Western Australia. *Bull. Geol. Surv. W. Aust.* **95**.

McKinstry, H. E. (1949).—"Mining Geology." 2nd Ed. (Prentice-Hall: New York.)

Parker, J. M. (1942).—Regional systematic jointing in slightly deformed sedimentary rocks. *Bull. Geol. Soc. Amer.* **53**: 381-408.

Pincus, H. J. (1951).—Statistical methods applied to the study of rock fractures; quantitative comparative analysis of fractures in gneisses and overlying sedimentary rocks of northern New Jersey. *Bull. Geol. Soc. Amer.* **92**: 81-130.

Prider, R. T. (1941).—The contact between the granitic rocks and the Cardup Series at Armadale. *J. Roy. Soc. W. Aust.* 27: 27-55.

——— (1948).—The geology of the Darling Scarp at Ridge Hill. *J. Roy. Soc. W. Aust.* 32: 105-129.

——— (1952).—South-west Yilgarnia. Sir D. Mawson Anniv. Vol. Univ. Adelaide: 143-151.

Thomson, B. P. (1942).—The geology and physiography of the Wongong-Cardup area. *J. Roy. Soc. W. Aust.* 27: 265-283.

Thyer, R. F. (1951).—Gravity traverse near Bullsbrook, W.A. Rec. Bur. Miner. Resour. Aust. No. 45.

Wallace, R. E. (1952).—Geology of shearing stress and relation to faulting. *J. Geol.* **59**: 118-130.

Wilson, A. F. (1958).—Advances in the knowledge of the structure and petrology of the Precambrian rocks of south-western Australia. *J. Roy. Soc. W. Aust.* **41**: 57-83.